March 2017

Technical Explanatory Note on Sediment Basin Design
prepared by Grant Witheridge

Catchments & Creeks Pty Ltd
ABN 34 078 164 119

The Mechanics Of Sediment Basin Operation

1. Introduction

This report provides an overview of the hydraulics of construction site sediment basins. The aim of the report is to explain, in simple terms, the fluid mechanics that determines how sediment basins are sized and operated, and to outline the design philosophy behind the new IECA Australasia sediment basin design guidelines (Appendix B) released in 2017.

Sediment basins can be classified using various naming systems. In the past these classification systems have been based on either the type of soil/sediment that the basins are designed to treat (e.g. Type C, D & F), the drainage conditions within the basin (e.g. wet & dry basins), or the hydraulic conditions that exist during the normal operation of the basin (e.g. continuous flow & plug flow basins).

Continuous flow operation means the basin continuously decants water while in operation. In these basins, the contained water is allowed to decant from the basin as soon as the flows reach the basin's outlet structure, even if the water has not reached the desired level of treatment. Continuous flow basins can operate as either free-draining basins, which are titled 'dry basins', or as non free-draining basins, which are usually titled 'wet basins'.

Plug flow operation means the basin is designed to prevent discharge during the initial 'treatment' phase of the basin, or while the basin is filling to a predetermined volume. The operation of these basins normally occurs in three phases: (i) inflow, (ii) settlement and (iii) decent; however, these phases can overlap.

It is important to note that once a plug flow basin reaches its 'full' volume, it then begins to operate as a continuous flow basin; however, the basin will not freely drain to an empty condition once the inflow stops. Instead, the basin will usually drain back to its designated full condition, after which the basin may or may not need to be manually drained to its designated empty condition.

In the new IECA guidelines, sediment basins are classified as Type A, B, C & D basins. This classification breaks away from the traditional soil-based classification of Type C for coarse grained soils, Type D for dispersive soils, and Type F for fine grained soils; and instead adopts a simple alphabetic classification that retains the title and function of both the Type C and D basins. The operation of Type F basins was considered to be so similar to Type D basins that the term was discontinued.

2. Terminology

The terminology used to describe the various components of a sediment basin can be controversial because the mechanics of these basins overlaps several fields of science and engineering—each profession having its own preferred terminology. The mechanics of construction site sediment basins also shares a lot of similarities with the fluid mechanics of wastewater treatment systems, which can also incorporate continuous and plug flow systems.

The terminology adopted within this paper is not wholly consistent with that used in Auckland, New Zealand or the USA to describe the sediment basins or by the wastewater industry to describe settling ponds. Figure 1 identifies some of the terms used within this paper.

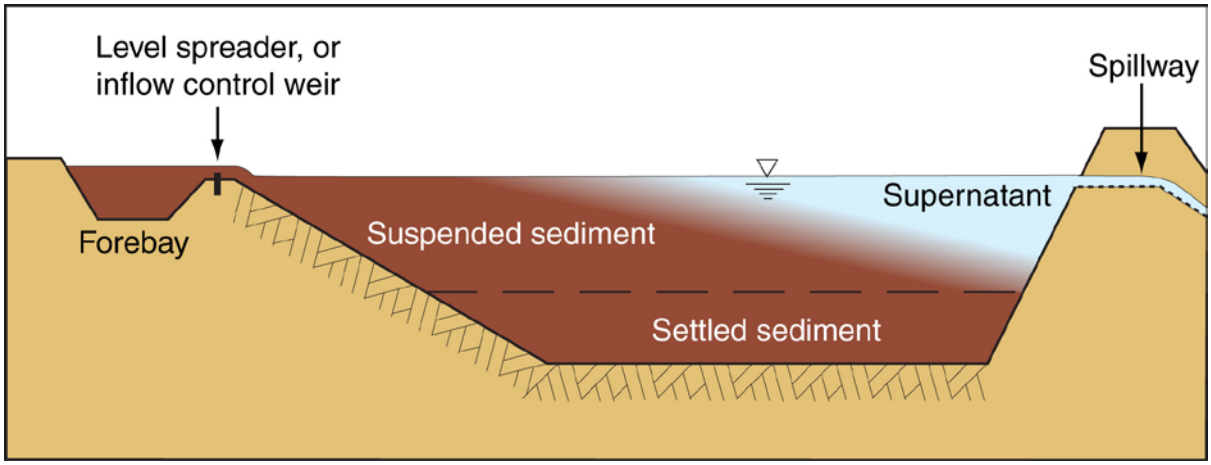

Figure 1 – Adopted terminology for sediment basins

3. The mechanics of 'continuous flow' sediment basins

The mechanics of continuous-flow sediment basins is the most basic of all sediment basins. These basins operate with a continuous flow of water passing through a settling pond that has been sized to achieve sufficient residence time to allow the settlement of a specified particle size.

It is generally not sufficient for the sediment particles to only partially settle before they reach the decent end of the basin; instead, it is usually necessary for the particles to fully settle to the floor of the basin so that they can 'adhere' to the rest of the settled sediment. It is only through this action that the settled sediment can resist the shear forces resulting from the clear supernatant flowing above the sediment.

In its most basic form, a continuous flow basin is only suitable for the treatment of waters containing sediment particles that exhibit good settling properties. In order for a clayey sediment to have good settling properties, most of the clay particles need to be bound into small 'aggregates' or 'peds'. If the soil is unstable in water, or has been heavily disturbed by mechanical equipment, then there is a greater risk that the individual clay particles will break free of these natural peds and stay suspended as the flow passes through the sediment basin.

It is for the above reasons that continuous flow sediment basins are only considered suitable for the treatment of good-settling, coarse-grained soils (i.e. soils that are both non-dispersive, and have minimal fines). Consequently, these sediment basins have traditionally been termed Type C basins ('C' for coarse grained soils).

In order to improve the ability of Type C basins to capture fine sediment particles, either a geotextile or aggregate filter can be incorporated into the basin's outlet structure (usually a 'riser pipe'). In theory this means that the finer sediment particles do not need to fully settle to the floor of the basin before the fluid reaching the outlet; however, it is generally recognised that neither a geotextile or aggregate filter is sufficient to capture and retain most of the clay-sized particles. Consequently, Type C sediment basins have rarely performed well on Australian construction sites given the fine and dispersive nature of many Australian soils.

Further improvements can be made to the performance of these basins through the integration of a floating, skimmer-type decent system, which aims to decent the 'cleanest' water from the upper surface of the settling pond.

Figure 2 demonstrates the operation of continuous-flow sediment basins.

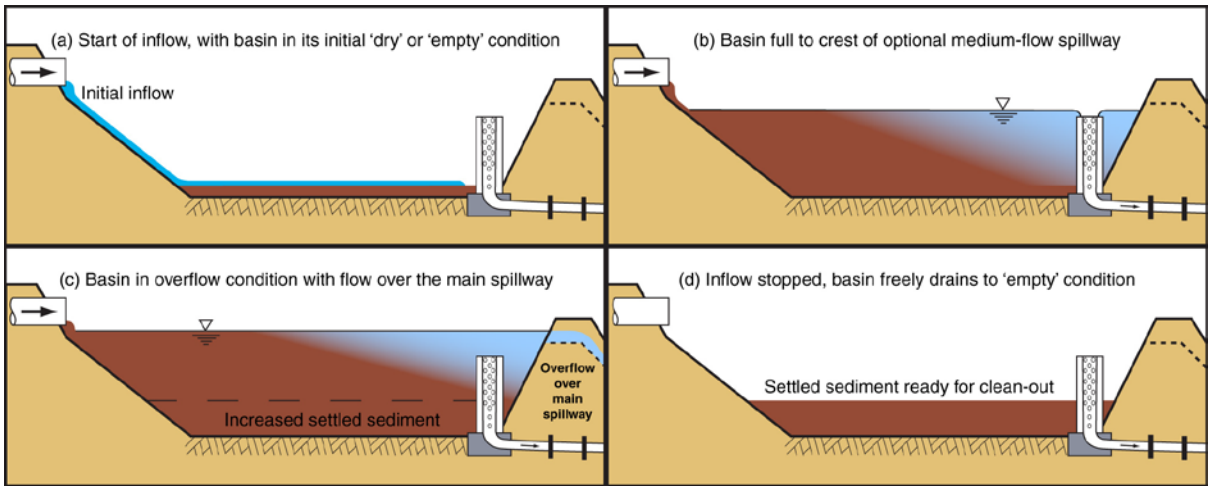

Figure 2 – Typical stages of operation for a continuous-flow sediment basin

The sizing of continuous-flow sediment basins is based on the idealised settlement characteristics of sediment particles passing uniformly through a rectangular basin (i.e. uniform, non-turbulent flow conditions exist throughout the basin).

4. The mechanics of 'plug flow' sediment basins

The mechanics of a plug-flow sediment basin is based on a staged approach to water treatment. The first stage is the capturing of the inflow, the second stage is the settlement of the retained fluid, and the final stage is the decanting of the clear supernatant leaving behind the settled sediment.

There are, however, two modes of operation for most plug-flow basins. The first mode of operation is when the volume of storm runoff entering the basin is less than the available basin volume, which relates to the case described above. This means the basin will not overflow during the basin's operation.

Figure 3 demonstrates the basic operation of a plug-flow sediment basin during the first mode of operation (i.e. no uncontrolled overtopping).

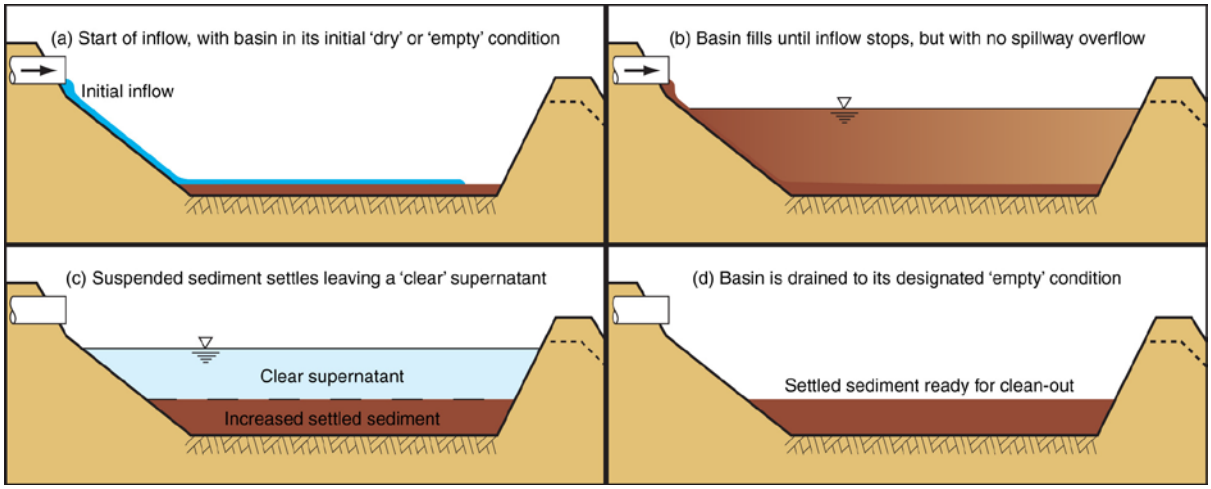

Figure 3 – Typical stages of operation for a non-overtopped, plug-flow sediment basin

The second mode of operation is when the volume of runoff entering the basin is greater than the available basin volume. This means the basin reaches its 'full' capacity and overflows begin to occur during the filling and/or settling stages of its operation. During this mode of operation the basin's performance mimics that of a continuous-flow sediment basin.

Entering this second mode of operation does not necessarily mean that the basin has failed, or that the overflow will necessarily fail to meet the desired water quality standard, but it is normal for the water quality to slowly decline as this mode of operation continues.

Plug-flow basins can be designed solely for the first mode of operation, in which case the size of the basin is based on a specified volume of runoff, which is normally based on a probable storm frequency (e.g. Type D basins). Alternatively, plug-flow basins can be designed for both modes of operation, in which case the basin is sized for a specified volume, as well as a specified minimum settling pond surface area (e.g. the new Type A basins).

Plug-flow basins have traditionally been used to treat waters that either contain significant quantities of fine-grained sediment, or significant quantities of dispersive clays.

5. The mechanics of Type A sediment basins

In 2016, IECA Australasia introduced a new sediment basin design, the Type A basin, which was based on the high efficiency sediment basins developed in Auckland, New Zealand. Key requirements of the Auckland basin design include:

- On earthwork sites with slopes less than 10% and less than 200 m in length, the sediment basin has an equivalent volume of 2% of the contributing catchment (i.e. 200 m^3 for each ha of contributing catchment).
- On sites with slopes greater than 10% and/or 200 m in length, the sediment basin has an equivalent volume of 3% of the contributing catchment (i.e. 300 m^3 for each ha of contributing catchment).
- Sediment clean-out is required when the volume of retained sediment reaches 20% of the basin's design volume. Thus the sediment storage volume is taken as 20% of the pond volume, and this sediment storage volume is included within the specified basin volume of 200–300 m^3 per hectare of contributing catchment.
- A 'dead storage' volume of 30% of the total settling pond volume is to be allocated. This is the non-decant volume located below the low-flow decent system. This volume is retained to help dissipate inflow energy during the initial filling of the basin. Typically this volume consists of the lower 0.4 to 0.8 m of the pond, and includes the nominated sediment storage volume of 20% of the total settling pond volume.
- The recommended decant rate is 3 litres/second/ha of contributing catchment.
- If two floating decant arms are required, the lower arm must decant throughout the full live storage depth, and the upper arm should only operate through the upper 50% of the live storage depth. If three decant arms are used, then the operating range of each arm should be: 100% of live storage, 67% and 33%.
- The length to width ratio of the settling pond is no less than 3:1 and no greater than 5:1.
- The settling pond depth (including the designated sediment storage zone) may be 1 to 2 metres, but no deeper than 2 m.
- Ideally, drainage catchments should be limited to a maximum of 5 ha per basin.

As previously discussed, the terminology adopted throughout this paper is not wholly consistent with that used in Auckland. For the purposes of clarity, Figure 4 demonstrates some of the terms used in Auckland in relation to the above dot points.

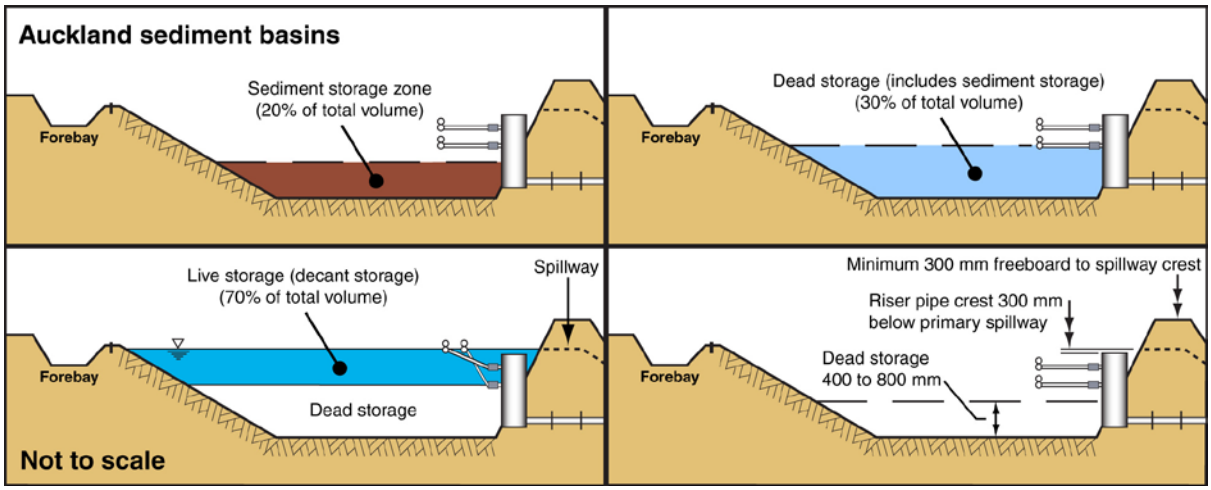

Figure 4 – Terminology as used for the Auckland sediment basins

Developing a design procedure for the new Type A basins involved establishing a mathematical relationship between the sizing of sediment basins in Auckland, and the key hydrological parameters associated with the operation of these basins in Auckland. This meant that these basins could now be sized appropriately for various climatic regions in Australia.

The mechanics of a Type A sediment basin is described below and shown in Figure 5.

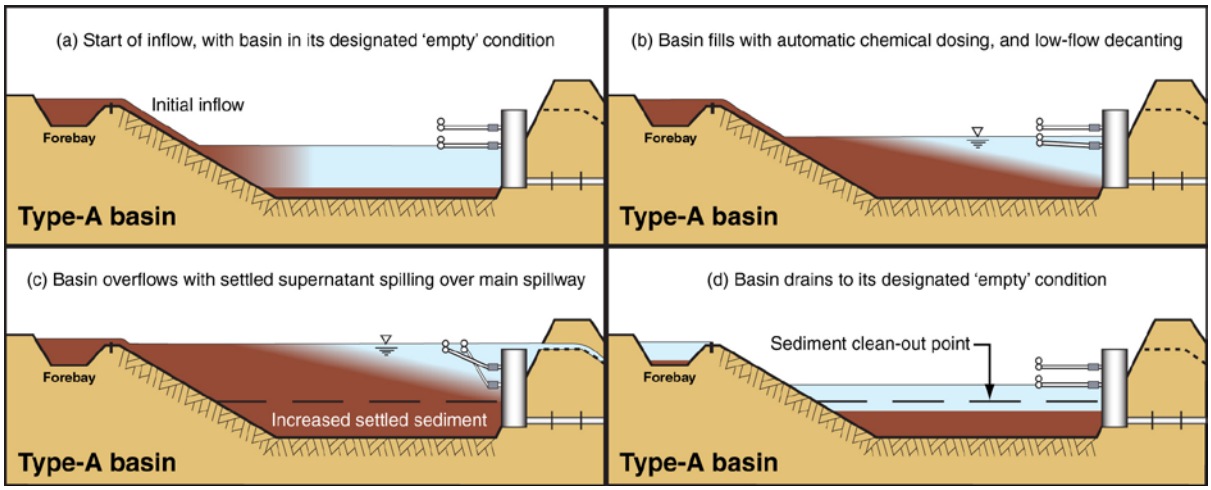

Figure 5 – Typical stages of operation for a Type A sediment basin

First mode of operation—basin operation without overflow:

- The settling pond begins to fill while the water level remains below the elevation of the primary overflow spillway. During this stage it is critical for the inflow to be uniformly distributed across the width of the basin, and for the inflow to have low levels of turbulence, thus allowing for optimum particle settlement.
- If the starting water level is at the designated 'empty' condition, then the floating, low-flow decent system begins to decant water almost immediately after the water first enters the basin.

Technical note 1:

Even though a floating skimmer pipe collects water from the upper surface of the settling pond, it is important to note that this does not mean that only surface water will be drawn towards the outlet. Supernatant will flow towards this decent pipe from a full range of depths, meaning that water can be drawn up towards the skimmer pipe from a metre or more below the water surface.

'Selective withdrawal' is a particular type of decanting. It is a process where water is selectively withdrawn from a specific layer or elevation within a stratified fluid. Large lakes and water supply dams can contain several stratified layers of water, each with a different water temperature and/or density.

However, fluid stratification is a condition that only occurs in certain circumstances within sediment basins. This means that the majority of the water flowing towards a skimmer pipe will come from the full depth of the 'clear' supernatant, with a small quantity of water possibly being extracted from within the settling floc blanket.

- If the water level in the settling pond continues to rise, then eventually more of the low-flow skimmer pipes will be engaged (depending on the design of the low-flow outlet structure).
- Depending on the design of the riser pipe outlet, it is possible that the crest of the riser pipe will act as a medium flow spillway (Figure 2b). In the Auckland system, this riser pipe consists of a 150 mm diameter pipe, and its crest is set 300 mm below the primary spillway crest. This design means that the crest of the riser pipe operates as another component of the low-flow decant system. In Australian, this riser pipe typically has a larger diameter, and it may not always be appropriate for the crest of the riser pipe to be set 300 mm below the spillway.

Second mode of operation—basin operates with a degree of overflow:

- If the water level in the settling pond exceeds the elevation of the spillway crest, then water will discharge freely over the spillway. Again it is important to note that similar to the low-flow skimmer pipes, the spillway will not just 'skim' clear supernatant from the top of the settling pond, but instead, water can be drawn towards the spillway from a wide range of depths.
- Because the basin's total decent (low-flow pipes plus spillway) has now increased, the interface between the suspended sediment and the clear supernatant will move closer towards the basin's outlet (see Figure 5c).
- If the basin's decent continues to be high, then eventually the suspended sediment will reach the skimmer pipes and the overflow spillway, and the basin will reach a condition of water quality failure.

Third mode of operation—inflows cease and the basin is de-watered:

- Once inflows to the basin cease, the basin will rapidly drain to the elevation of the spillway crest, then slowly drain to the lowest decent setting of the floating decant pipes.
- If, at the point when the basin stops spilling over the spillway, the quality of the decant water from the skimmer pipes does not meet the required water quality (typically 50 mg/L or the equivalent NTU), then the low-flow decent system can be shut-off to allow the sediment basin time to achieve optimum supernatant water quality.
- When a suitable supernatant water quality is achieved, the basin is allowed to de-water to its designated 'empty' condition, which is usually set at the lowest travel point of the lowest skimmer pipe.
- It is noted that circumstances can exist where the basin's operating conditions will require the basin to be de-watered immediately, even if the supernatant water quality fails to meet the desired standard. Such conditions may exist in the event of an imminent storm that is expected to refill the basin.

5.1 Numerical analysis of the Auckland basin performance

The following is a summary of the mathematical analysis of the Auckland basins that was developed during the recent IECA review. Initially an investigation was conducted into the continuous flow mode of operation (i.e. a full basin with inflow = outflow = 3 litres/second/ha). Then an investigation was conducted into the plug flow operation of the basin (i.e. when a storm does not cause the basin to overflow).

If it is assumed that:

- the Auckland basins allow the full settlement (to the basin floor) of the critical particle size; and
- the shortest residence time occurs when the basin is full, but not overflowing, and the inflow rate equals the low-flow skimmer pipe decant rate of 3 litres/second/ha; and
- the basin's hydraulic properties can be represented by a continuous flow process; then:

using Stakes' Law it was determined that the Auckland basins were sized for an equivalent 0.005 mm particle size. It is noted that for a traditional Type C sediment basin, the critical particle size is typically 0.02 mm, which is four times the size of the equivalent particle size attributed to the Auckland basins. This could partially explain the increased efficiency of the Auckland sediment basins.

The next step was to analyse the volume of the Auckland basin to see if a relationship could be developed that could link the basin volume to a particular storm event.

It is noted that the total volume of a sediment basin (V_B) is made up of the settling volume (V_S) plus the nominated sediment storage volume (V_{SS}), which is that part of the basin's volume that is made available for storage of the settled sediment. This means the sediment storage volume cannot be considered an 'effective' part of the basin's settling volume. The Auckland design process nominates 20% sediment storage volume, which is included within the nominated total volume of 300 m^3 per hectare. Therefore, the effective settling volume (V_S) is only 80% of 300 m^3, which is 240 m^3 per hectare.

A simplified Excel-based analysis of the Auckland basins indicated that the specified settling volume of 240 m^3 per hectare is likely to provide non-overtopping operating conditions for a storm frequency of between 1 and 1.5 years. This means that during a 1 in 1 year storm, the basin is likely to fill, but not overtop; and that the desired discharge water quality is likely to be maintained throughout the basin's operation during such a storm.

The key outcomes from the Auckland sediment basin analysis can be summaries as:

- the performance of the Auckland basins is related to both the basin's settling volume (V_S) and the basin's surface area (A_S).
- the basins appear to have sufficient volume to cater for most 1 in 1 year to 1 in 1.5 year storms without overtopping
- with respect to the basin's surface area and low-flow decent rate, the effective critical particle size for a continuous flow operation is 0.005 mm, which is much finer than traditionally used in Australian sediment basins.

5.2 Key design variables that need to be managed for Type A basins

In order to optimise the design of a Type A basin it is necessary to identify the key design variables, the limits and constrains of these variables, and the influence these variables have on the design of the basin. A summary of the key variable is presented in Table 1.

Table 1 – Summary of key design variable

Variable	Typical value	Range	Influence of variable on basin design
Design storm	1 in 1 year	1 to 5 yr ARI	• Increasing the design storm severity increases the required basin volume
Catchment area	—	—	• Desirable < 5 ha per basin
Length:width ratio	3:1	2:1 to 10:1	• Important when overtopping occurs
Total pond volume	—	—	• The total pond volume (V_T) = settling volume (V_S) + lower storage (V_L)
Settling zone depth	1.5 m	0.6 to 3.0 m	• Minimum depth of 0.6 metres
Lower storage volume (dead storage, V_L)	40% of settling zone volume, (V_S)	N/A	• Includes the sediment storage zone • Minimum $V_L = V_{SS}$ + 10% (V_S) • Approximately 30% of total volume
Sediment storage volume (V_{SS})	30% of settling zone volume	N/A	• Minimum V_{SS} = 30% (V_S) • Approximately 20% of total volume
Low-flow decent rate	—	0.3 to 0.9 (L/s/ha)	• Increasing the low-flow decent rate can reduce the required basin volume
Critical particle size	0.01 mm	0.005 to 0.02	• Only critical when the settling zone depth is greater than the 'critical' value, which causes the minimum pond area (A_S) to become critical
Water temperature	Depends on local conditions		• Based on the coldest 'wet' month
Maximum allowable supernatant velocity	1.5 cm/s	1.0 to 2.0 cm/s	• Depends on whether the sediment floc is suspended or fully settled

(i) Settling volume (V_S)

- The settling volume directly impacts on the settling pond surface area; however, if the settling pond depth exceeds its 'optimum' value, then the surface area of the settling pond will be governed by the minimum pond surface area requirement.
- The settling volume can be altered by modifying the following variables:
  - the low-flow decent rate, either by modifying the flow rate per decent arm, or increasing the number of decent arms
  - the nominated design storm frequency (e.g. 1 yr, 2 yr or 5 yr ARI).

(ii) Lower storage (V_L)

- The required lower storage volume directly impacts on the total basin volume.
- The lower storage volume incorporates the sediment storage zone, plus a volume above the settled sediment that is normally retained between storms, but this water can be used on the site for such things as dust control and plant watering if desired.
- If this upper layer of the lower storage volume is <u>not</u> retained between storms, then the basin will be able to receive a certain volume of inflow before the basin's floating decant system begins to discharge flows.
- If this upper layer of the lower storage volume is retained between storms (i.e. not used for dust control, etc.), then this clear supernatant liquor will be the first water decanted from the basin at the start of the next storm. The absence of this retained supernatant will likely mean that turbulence from the initial inflows will cause the re-suspension of previously settled sediment, meaning that the initial discharge from the basin **may** exceed the desired water

turbidity. This is an issue that will need to be monitored once the use of these basins becomes more widely spread.

- The lower storage volume can be altered by modifying the requirements for the sediment storage volume.

(iii) Sediment storage volume (V_{SS})

- The required sediment storage volume directly impacts on the total basin volume.
- Increasing the allowable sediment storage volume will increase the allocated lower storage volume.
- Increasing the allowable sediment storage volume can possibly decrease the frequency of basin maintenance (i.e. reduce the frequency of de-silting operations).

(iv) Low-flow decent rate

- The low-flow decent rate impacts on the required settling volume, and therefore the total volume of the settling pond.
- The allowable low-flow decent rate may be influenced by:
  - the maximum allowable supernatant scour velocity that could cause settled sediment to be drawn up towards the decent pipes; and
  - the knowledge that increasing the low-flow decent rate will increase the minimum required surface area of the settling pond; especially when it is considered that it is desirable to avoid those circumstances where the settling pond surface area is governed by the minimum surface area requirement.

(v) Width of the emergency overflow spillway

- The width of the emergency spillway can directly influence the risk of settled sediment being drawn up and dragged over the spillway by friction forces (scour) caused by the contraction of the supernatant flow as it approaches the spillway. The design limits resulting from this hydraulic issue are **not** currently fully understood. Consequently, this is an issue that will require further monitoring.
- As discussed above, as surface waters move towards the spillway, the width of the flow must contract from the width of the basin to the width of the spillway. This contraction of flow causes a direct increase in flow velocity, which technically increases the risk of these surface water disturbing the settled sediment below. However, the saving grace is that this contraction of flow normally occurs over an inclined batter leading to the spillway crest. It is therefore possible that the upper surface of the settled sediment blanket is located well away from the crest of the spillway (due to the both the depth of the blanket and the inclined face of the earth batter leading up to the spillway). This means that disturbance to the sediment blanket may not occur. This is an aspect of sediment basin fluid mechanics that is not well understood, and only field testing will identify if scour of the settled sediment blanket will become a problem.

(vi) Design storm frequency

- The design storm frequency directly impacts on the required settling pond volume and the settling pond surface area. Increasing the severity of the design storm will improve the expected long-term water quality outcomes, but will significantly increase the cost of the basin's construction.

(vii) Critical particle size

- Selection of the critical particle size directly impacts on the minimum settling pond surface area requirement, but may not necessarily alter the required basin volume. Decreasing the critical particle size will likely improve the expected long-term water quality outcomes, but

may increase the cost of the basin's construction depending on the nominated basin depth.

(viii) Settling pond water temperature

- The temperature of the settling pond water is usually governed by the air temperature during storm events. The nominated water temperature is usually set as the air temperature during the wet season; however, this rule may not apply as temperatures approach zero.
- Reducing the water temperature reduces the settling velocity of sediment particles, resulting in an increase in the required settling pond surface area.

5.3 The optimum settling pond depth and its importance to Type A basin design

The sizing of a Type A basin is governed by the requirements for both a minimum settling volume (V_S), and a minimum settling zone surface area (A_S). Under normal circumstances, a basin designer should try to optimise the basin's dimensions such that both the pond volume and surface area are minimised.

For a given low-flow decant rate (Q_A), there is an 'optimum' settling zone depth (D_S) that will allow the minimum settling volume and minimum settling zone surface area requirements to be achieved concurrently. Conversely, for a given settling zone depth, there is an 'optimum' low-flow decant rate that will also allow both of these design requirements to be achieved concurrently.

If site conditions place restrictions on the total depth of the sediment basin (D_T), then this will directly impact upon the maximum allowable depth of the settling zone (D_S); however, the relationship between the settling zone depth and the total pond depth is complex, and depends on a number of factors.

5.4 Determination of basin sizing equations that could be utilised across Australia

The original design aim of the Type A basin was to replicate the performance of the Auckland basins. A simplified Excel flow model was used to analyse the performance of the Auckland basins as they are operated in Auckland. The Excel model incorporated the several assumptions are discussed below. Adopting these assumptions means that the real life outcomes of these Type A basins cannot be guaranteed. Ultimately the performance of Type A basin will be determined from in-situ testing and design optimisation.

The 'assumptions' incorporated into the Excel model include:

- Rainfall is uniform over the drainage catchment, and is uniform throughout the storm's duration.
- The drainage catchment is approximately rectangular such that the rate of increase in 'inflow' into the basin is steady from time '0' to its peak discharge at time 'TB', which is equal to the 'time of concentration' of the catchment (i.e. the point in time when all of the catchment is contributing flow into the basin).
- The inflow hydrograph can be represented by a simple trapezoidal time–discharge profile (Figure 6) with a constant rise in discharge to the peak, a constant peak inflow that is maintained for a sufficient period to allow the inflow of the storms runoff volume, and then a linear decline in the inflow rate until a zero inflow is reached at time 'TE'.

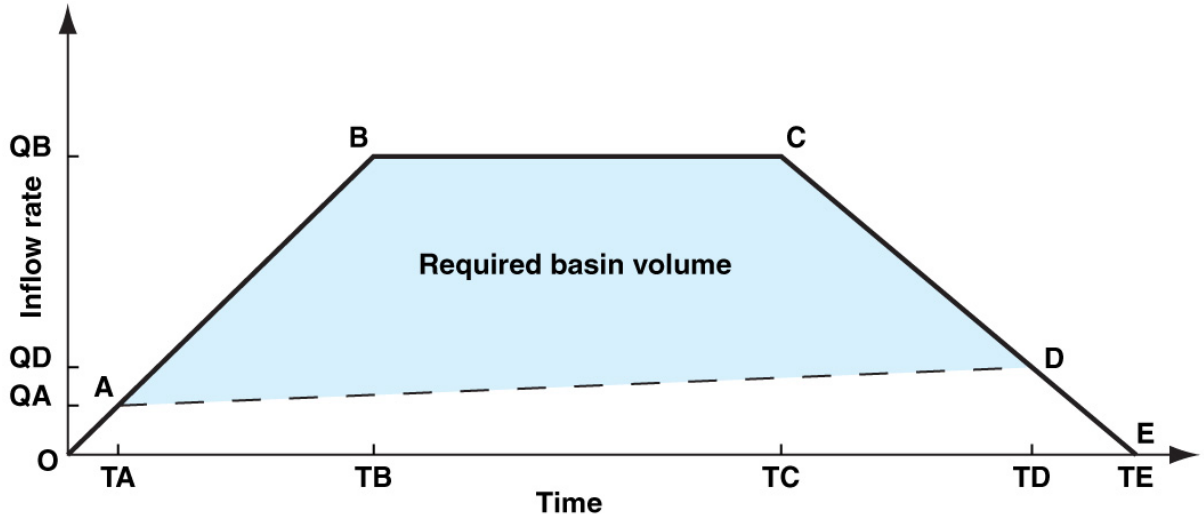

Figure 6 – Adopted basin inflow hydrograph

- The storm duration (T) is assumes to be equal to the time of concentration for the catchment (T_C); thus the peak discharge can be estimated using the Rational Method, Q_{PEAK} = C*I*A.
- The total volume of the inflow hydrograph is equal to the total rainfall depth (I*T) times the catchment area (A) times the volumetric runoff coefficient (C_V); thus **V** = (C_V*I*T*A). The volumetric runoff coefficient (C_V) was estimated by developing a best fit equation for a clayey soil (soil Group D in Table B7 of IECA (2008)).
- Low-flow begins to discharge from the basin as soon as flows enter the basin (i.e. there is no initial filling of the basin). This means the analysis will theoretically under-estimate the required storage volume.
- It is noted that this Excel-based analysis did not take into account the volume of the retained supernatant (i.e the dead water storage minus the nominated sediment storage volume, which was taken as 25% of the settling zone volume). This means the total volume of the sediment basin will be effectively 15% of the settling volume larger that that determined within this analysis. However, it is also noted that the existence of this additional volume will not alter the performance of the basin with respect to the Excel analysis.

The sizing of Type A basin is based on satisfying the following three-point test:

(i) a minimum settling pond volume, V_S

(ii) a minimum settling pond surface area, A_S

(iii) a maximum supernatant flow velocity to prevent disturbance of the settled sediment floc.

(i) Minimum settling volume, V_S:

The minimum settling volume is determined from the following equation:

$$V_S = K \,.\, A \,(I_{X\,yr,\,24\,hr})^{1.8} \qquad \text{(Eqn. 1)}$$

where:

V_S = minimum settling volume [m^3]

K = equation coefficient that varies with the design event (X) and the chosen low-flow decent rate (Q_A) refer to Table 2

A = area of the drainage catchment connected to the sediment basin [ha]

$I_{X\,yr,\,24\,hr}$ = the average rainfall intensity for an X-year, 24-hour storm [mm/hr]

X = the nominated design event (ARI) expressed in 'years'

Table 2 – Type A basin sizing equation coefficient 'K'

Low-flow decent rate 'Q_A'		Coefficient 'K' for specific design events		
L/s/ha	**m^3/s/ha**	**1 year**	**2 year**	**5 year**
2	**0.002**	45.0	46.0	46.9
3	**0.003**	34.5	36.7	39.5
4	**0.004**	28.4	30.8	33.9
6	**0.006**	22.7	22.9	26.0
8	**0.008**	17.6	18.8	20.9
9	**0.009**	16.2	17.4	19.3

(ii) Minimum surface area requirement, A_S:

The basin's settling zone must satisfy a minimum surface area (A_S) measured at the mid-elevation of the basin's settling zone.

$$A_S = K_A Q_L \qquad \text{(Eqn. 2)}$$

where: A_S = minimum mean-depth pond surface area [m^2]

Q_L = the maximum low-flow decent rate prior to flows overtopping the emergency spillway [m^3/s] = Q_A*A

Q_A = the low-flow decent rate per hectare of contributing catchment [m^3/s/ha]

A = area of the drainage catchment connected to the basin [ha]

K_A = equation coefficient for a Type A basin (refer to Table 3)

$$K_A = (18.\mu) / (g.(s-1).d^2) \qquad \text{(Eqn. 3)}$$

where: μ = kinematic viscosity of the water at a given temperature [m^2/s]

g = acceleration due to gravity [m/s^2]

s = specific gravity of critical sediment particle (assume: s = 2.65 for clay soils)

d = diameter of critical sediment particle (default: d = 0.01 mm) [m]

Table 3 – Equation coefficient (K_A) for 0.01 mm particle size with specific gravity of 2.65

Recommended water temperature (°C)	10	15	20	25	30
Equation coefficient, K_A	14,520	12,670	11,150	9930	8900

The nominated critical particle size (d_p = 0.01 mm) should be treated only as a design variable, not an performance standard. Consequently it should **not** be assumed that the basin will only be capable of capturing particles larger than 0.01 mm. This design variable is used simply because it allows the incorporation of important design variables such as water temperature, water viscosity, and residence time.

(iii) Maximum supernatant velocity, $V_{Surface}$:

It is important to ensure that the maximum clear water (supernatant) velocity above the settled sediment floc ($V_{Surface}$) does not exceed a velocity that will cause disturbance to the settled sediment.

From the field testing performed on the decanting of wastewater treatment plants (Witheridge & Wilkinson, 1989), the allowable supernatant velocity is currently assumed to be 1.5 cm/s. Field testing of Type A sediment basin may lead to a modification of this allowable supernatant velocity.

6. The mechanics of Type B sediment basins

The design of Type B basins is based on a modification of the Type A basin design. The basic operation of a Type B sediment basin is shown in Figure 7.

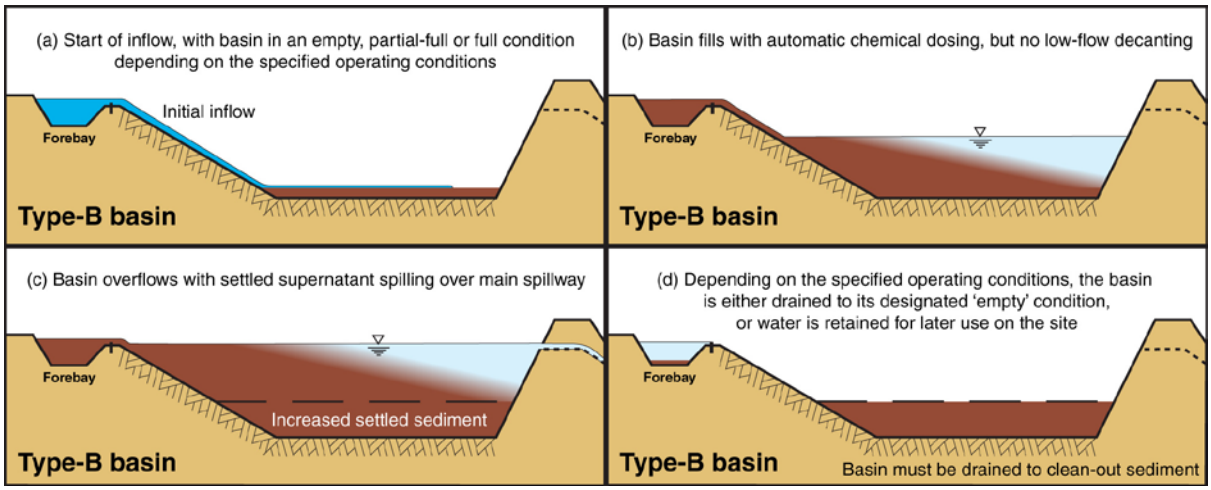

Figure 7 – Typical stages of operation for a Type B sediment basin

Two design options have been prepared, and the choice between these two options depends on the expected floc settling characteristics. The first design option, Option 1B, is based on setting a minimum settling pond surface area (A_S) and depth (D_S) such that the settled sediment has sufficient time to settle to the floor of the basin, which means the sediment floc is able to form a slightly compacted sediment blanket. It is assumed that allowing the sediment to fully settle the basin floor will increase the resistance of the sediment blanket to the effects of 'scour' caused by the decanting of the supernatant.

The second design option, Option 2B, is based on providing sufficient time to allow the sediment floc to settle at least 600 mm. This design option results in a basin with a greater depth, but smaller surface area, than design Option 1B.

Both design options assume that the layout of the sediment basin has incorporated the same hydraulic efficient characteristics as a Type A basin, including:

- energy dissipation / mixing forebay
- automatic dosing with flocculant or coagulant
- inflows passing over a level spreader
- rectangular settling pond with no 'deadwater' zones.

The minimum dimensions of a Type B basin must be based on concurrently satisfying the minimum average surface area (A_S), the minimum settling zone depth (D_S) or depth to the settled floc (D_F), and the maximum allowable supernatant velocity (v_S) requirements.

Unlike a Type C basin, the sizing of the settling pond surface area (A_S) does not incorporate a 'hydraulic efficiency correction factor' (H_e). This is because of the required hydraulic efficient design characteristics listed above ensures that inflows into the settling pond are evenly-distributed and have low-turbulence, thus $H_e = 1.0$.

If laboratory testing of the sediment-flocculant partnership indicates a poor sediment settlement rate, such as less than 100 mm in 15 minutes, then the minimum depth of the settling zone (D_S) is governed by the minimum recommended depth of 0.5 m, which increases the volume of the settling zone compared to those basins that utilise a more effective flocculant.

Type B basins do not incorporate a low-flow decant system, consequently the overflow spillway functions as the sole point of discharge from the basin. In order to reduce the risk of the re-

suspension of settled or still-settling sediment, the overflow spillway on a Type B basin should be given the maximum practical width. Ideally the maximum allowable supernatant (clear liquor) velocity upstream of the overflow spillway should be 1.5 cm/s (0.015 m/s) during the basin's design storm (i.e. Q = 0.5 Q1); however, this may not always be practical for Type B basins. In such cases, designers should take all reasonable measures to achieve a spillway crest width just less than the top width of the settling zone.

The nominated settling zone depth for an Option 2B design needs to be within the range of 0.6 to 2.0 m. The greater the nominated depth, the smaller the required surface area of the basin, but the volume of the settling zone (V_S), and consequently the total basin volume, will essentially remain unchanged.

The minimum recommended settling zone depth for an Option 2B design is 0.6 m, which is an increase from the 0.5 m used in Option 1B. This is because the sediment floc in an Option 2B basin is considered to be still settling as it approaches the overflow spillway; whereas in design Option 1B the sediment floc is assumed to have fully settled, and thus more resistant to disturbance.

7. The mechanics of Type C sediment basins

The mechanics of a Type C sediment basin is based on the properties of a traditional settling pond. These basins operate with a continuous flow of water passing through the settling pond, which has been sized to allow the full settlement (to the bottom of the nominated settling zone) of a specified particle size.

The minimum 'average' surface area of the settling zone (A_S) is based on the following equation.

$$A_S = K_S H_e Q \qquad \text{(Eqn. 4)}$$

where:
- A_S = average surface area of settling zone = V_S/D_S [m^2]
- K_S = sediment settlement coefficient = the inverse of the settling velocity of the 'critical' particle size
- H_e = hydraulic efficiency correction factor
- Q = design discharge = 0.5 Q1 [m^3/s]
- Q1 = peak discharge for the critical storm duration 1 in 1 year ARI event
- V_S = volume of the settling zone [m^3]
- D_S = depth of the settling zone [m]

The basic operation of a Type C sediment basin is shown in Figure 8.

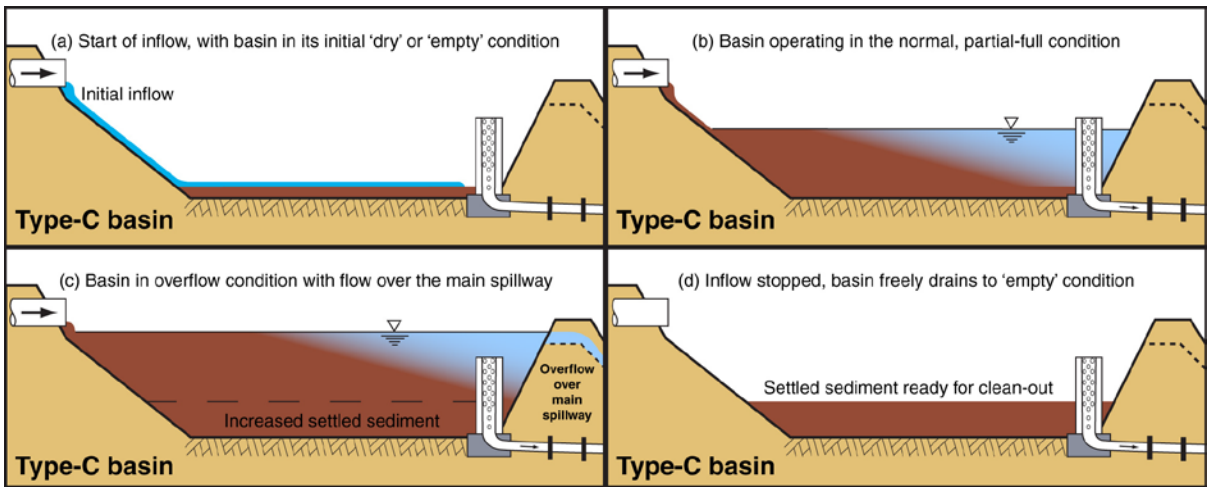

Figure 8 – Typical stages of operation for a Type C sediment basin with riser pipe

Type-C sediment basins typically adopt a design discharge of 0.5 times the peak 1 in 1 year ARI discharge (Q1), and a critical particle size of d = 0.02 mm (0.00002 m).

The hydraulic efficiency correction factor (H_e) depends on flow conditions entering the settling pond, and the shape of the basin.

The minimum recommended depth of the settling zone (D_S) is 0.6 m. The desirable minimum length to width ratio at the mid-elevation of the settling zone is 3:1. The use of internal baffles may be required in order to prevent short-circuiting if the length-to-width ratio is less than three.

The development of Equation 4 is based on a rectangular settling pond with **uniform** inflow (Q), width (W), depth (D) and length (L). The hydraulic analysis of such a settling pond provides the following outcomes:

- the average forward velocity: $V_H = Q/(D.W)$
- the travel time across the basin: $t_H = L/(VH)$
- thus, $t_H = (L.D.W)/Q$ = Volume/Discharge
- in other words, t_H = retention time

The assumption of 'uniform flow' means a hydraulic efficiency correction factor (H_e) of unity is adopted.

The falling velocity of a sediment particle depends on:

- particle size, shape and relative density
- water temperature (a factor of viscosity) assumed to be based on temperature of rainfall
- water motion (turbulence and up-flow caused by mass settlement of sediment particles)
- electro-magnetic forces (not considered in the Stokes' Law equation).

Stokes' Law (Equation 5) is typically adopted for the determination of the particle settling velocity.

$$V_p = (g.(s-1).d^2)/(18.\mu) = 1/K_S \qquad \text{(Eqn. 5)}$$

where: V_p = particle falling velocity [m/s]
s = specific gravity of particle
g = acceleration due to gravity [m/s^2]
d = particle diameter [m]
μ = kinematic viscosity of the water at a given temperature [m^2/s]

If the settling pond is sized such that the critical particle size settles to the bed (t_p) just before reaching the end of the basin, then:

$$t_H = t_p$$

or

$$t_H = (L.D.W.)/Q = D/V_p$$

thus

$$\text{Surface area } (A_S) = L.W = Q/V_p$$

So for a soil with critical particle size of 0.02 mm, and specific gravity of 2.6, and with a basin water temperature of 13º C, then $V_p = 0.000294$ m/s, and $K_S = 3400$, thus:

$$A_S = Q/0.000294 = 3400(Q) = K_S\,(Q) \qquad \text{(Eqn. 6)}$$

where: A_s = surface area of sediment basin at the base of the settling zone
Q = design storm peak flow rate; typically Q = 0.5 Q1

Q1 = peak discharge from the 1 in 1 year ARI design storm

If near-uniform flow conditions do not occur throughout the basin, then the required surface area (A_S) is determined from Equation 7, which is the same as Equation 4.

General design equation: $A_S = K_S H_e Q$ (Eqn. 7)

8. The mechanics of Type D sediment basins

Type D sediment basins operate as plug-flow settling tanks as demonstrated in Figure 9.

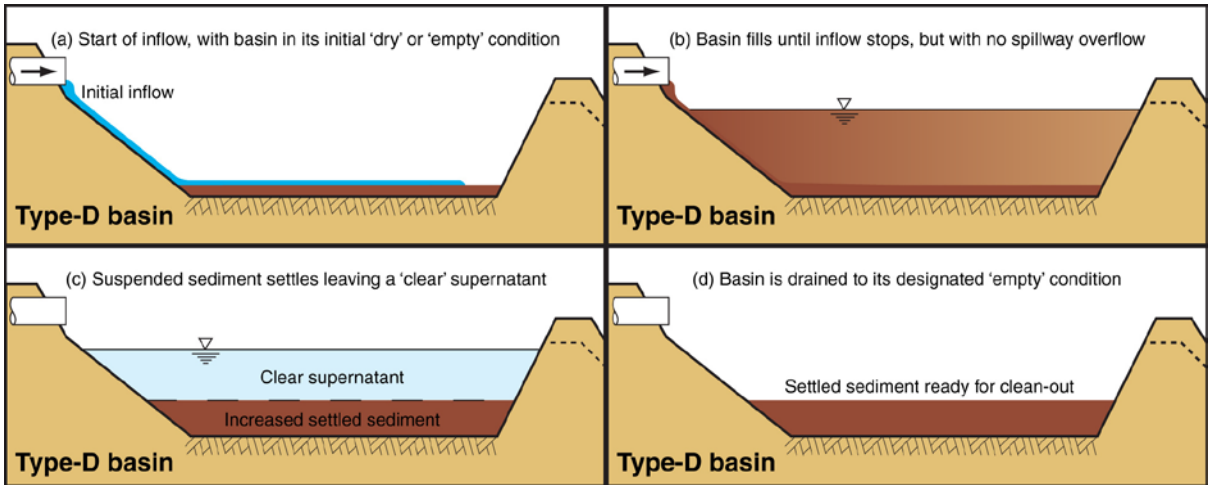

Figure 9 – Typical stages of operation for a Type D sediment basin

The minimum volume of the upper settling zone is defined by Equation 8.

$$V_S = 10.\ R(Y\%,5\text{-day})\ .\ C_V\ .\ A \qquad \text{(Eqn. 8)}$$

where: V_S = volume of the settling zone [m^3]
$R(Y\%,5\text{-day})$ = Y%, 5-day rainfall depth [mm]
C_V = volumetric runoff coefficient
A = effective catchment surface area connected to the basin [ha]

The minimum recommended depth of the settling zone is 0.6 m, or L/200 for basins longer than 120 m (where L = effective basin length). It is recommended that settling zone depths greater than 1 m should be avoided if the particle settlement velocity is expected to be slow.

The desirable minimum length to width ratio of 3:1 is also recommended for Type D basins. The length to width ratio is important for Type D basins because they operate as continuous-flow settling ponds (i.e. similar to Type C basins) once the flow begins to discharge over the emergency spillway.

Type D basins are typically designed for a maximum 5-day cycle—that being the filling, treatment and discharge of the basin occurs within a maximum 5-day period. In some tropical regions this may not be practical, and either a shorter or longer time frame may be required. The use of a shorter time period usually requires the application of fast acting flocculants that usually require a much higher degree of environmental management compared to the use of gypsum. The use of a longer time period will require the construction of a significantly larger basin.

Unlike permanent stormwater treatment ponds and wetlands, Type D basins are not designed to allow high flows to bypass the basin. Even when the basin is full, sediment-laden stormwater runoff should continue to be directed through the basin. This allows the continued settlement of coarse-grained particles contained in the flow. Such basin management practices may cause

some re-suspension and discharge of previously settled fine sediments during heavy storms, but the task of trapping the anticipated large volume of sand and coarse silts washed from a construction site is considered more important.

In effect, Type D basins are designed to produce high quality outflows during the more frequent lighter storms (i.e. storms less than the 1 in 1 year ARI storm), but to also allow the continued trapping of coarse sediments during the less frequent heavy storms (i.e. storms equal to, or greater than, the 1 in 1 year ARI storm).

The volumetric runoff coefficient (C_V) is **not** the same as the discharge runoff coefficient (C) used in the Rational Method to calculate peak runoff discharges. A volumetric runoff coefficient of 1.0 is typically applied to impervious surface areas, including open soil surfaces that have been compacted by construction traffic.

Grant M Witheridge
Director
RPEQ 3591
March, 2017